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Original scientific paper

Influence of the Incoming Solar Radiation on the Bone Mineral Density in the Female Adult Population in Croatia

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ABSTRACT

The relationship between the bone mineral density (BMD) in Croatian female adults and the average incoming solar radiation at the ground was investigated. The study included 387 volunteers of average age of 60 years from three different towns: Pula (n=128, age from 35 to 76), Krapina (n=141, age from 43 to 77), and Zagreb (n=118, age from 32 to 79). Apart from the different lifestyle, each of above towns is characterized by different incoming solar radiation, where values of 503.3 kJ cm^{-2}, 471.2 kJ cm^{-2} and 436.3 kJ cm^{-2} correspond to average annual radiation at the ground for Pula, Krapina and Zagreb, respectively. Heel BMD was measured by clinical bone sonometer (Sahara). On the average the BMD was highest for Pula (0.469 g cm^{-2}) and the lowest for Zagreb (0.433 g cm^{-2}). Similarly, the percentage of normal bones was the highest for Pula (46.1%) and the lowest for Zagreb (32.2%). Osteopenic bones were the most frequent for Zagreb (61.0%), while corresponding figures for Pula and Krapina were 46.9% and 43.6%, respectively. Osteoporosis varied from 6.8% in Zagreb to 11.4% in Krapina. A test of independence by contingency table confirmed at the significance level α=0.05 that probability of normal bone occurrence increases with the increase of incoming solar radiation. Results of the multiple regression analysis suggest the dependence of BMD on woman's age and weight, and incoming solar radiation at the place of habitation.

Key words: *epidemiology, solar radiation, bone mineral density, BMD, Croatia*

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Introduction

Bone mineral density (BMD) depends on various factors. It has long been known that racial or ethnic differences in BMD exist. For example, populations of African ancestry, whether living in Africa or North America have been shown to have greater bone densities than populations of European or Asian ancestry. Higher BMD is also found in Chinese women compared to Arizona women[1].

BMD declines with age[2–3]. Further, risk factors for BMD reductions prior to menopause are a low body weight and disordered eating[4–7]. However, in the case such as an anorexia nervosa, mechanism of the bone loss differs from that one in menopausal women. Therefore, it requires the development of the specific therapeutic strategies[5].

Adequate calcium intake in the presence of adequate vitamin D intake has been shown to be of great importance in preventing the bone loss[8–9], particularly in women in peri- or postmenopause[9]. To ensure adequate calcium absorption, a daily intake of 400–600 IU of vitamin D is recommended, either through sun exposure or through diet or supplementation[9].

Various studies address to the role of the sun exposure on the vitamin D levels[10–12] and/or on BMD[4,13–16]. They generally suggest negative effects of low sun exposure on vitamin D levels and/or BMD, though some of results are at the first sight surprising. For example, according to the recent study[8], hypovitaminosis D among the young otherwise healthy European population is more frequent in sunny Mediterranean countries than in some northern countries such as Norway. This is attributed to the limited quantity of vitamin D in food, sun exposure behavior and urban lifestyle with a high degree of pollution.

The aim of this study was to investigate if the existing differences in the available solar radiation at the ground at various locations in Croatia are large enough to produce differences in the BMD in female adult population. Additionally, the correlation between the various individual characteristics (such as height, weight, age and postmenopausal period) and the BMD was also examined. Finally, a multivariate model of the behavior of BMD on the basis of woman's age, weight and available solar radiation in the place of habitation is proposed.

Subjects and Methods

387 female volunteers living in three different towns in Croatia (Krapina, Pula and Zagreb) were studied. Each of the above towns is characterized by the different life-style. Krapina is a small continental town of less than 15,000 inhabitants, where agricultural activities, and consequent sun exposure, are still widespread. Pula is a coastal town and according to the 2001 census of population has more than 62,000 inhabitants. The capital of Croatia, Zagreb has more than 770,000 inhabitants and it is characterized with urban lifestyle.

Further, as listed in the Table 1, each of the towns concerned is exposed to the different amount of average incoming solar radiation at the ground level, where the largest and the smallest amounts are related to Pula and Zagreb, respectively. Radiation data for Zagreb are based on measurements[17], while data for Pula and Krapina are modelled. For this purpose the model of Nikolov and Zeller[18] is employed, where incoming solar radiation at the ground is calculated from the observed cloudiness, site latitude and altitude.

The study included 128 women from Pula (age from 35 to 76, average age 57.3), 141 women from Krapina (age from 43 to 77, average age 59.9) and 118 women from Zagreb (age from 32 to 79, average age 61.8). As illustrated in the Figure

TABLE 1
POSITIONS OF METEOROLOGICAL STATIONS AND CORRESPONDING AVERAGE ANNUAL SOLAR RADIATIONS AT THE GROUND. CORRESPONDING PERIODS AND REFERENCES FOR RADIATION DATA ARE ALSO LISTED

Station	Latitude	Longitude	Altitude (m)	Average annual solar radiation (kJ cm^{-2})	Period	Reference
Pula – airport	44°54'N	13°55'E	63	503.3	1978–1990 and 1993–1995	18
Krapina	46°08'N	15°53'E	202	471.2	1981–1988	18
Zagreb – Grič	45°49'N	15°59'E	159	436.3	1862–1990	17

1, the age of volunteers from Pula was the most frequently between the 51 and 55 years, while for Krapina it was between 56 and 60 years. On the other hand, the age of both, women from Zagreb and women from all three towns together was the most frequently between 61 and 65 years.

The heel BMD was measured by clinical bones sonometer (Sahara). Apart from BMD value and age, data on height, weight, menarche and occurrence of menopause were also collected. (Average values of above characteristics are listed in Table 2) The dependence between the BMD and the solar radiation was examined by the test of independence by contingency table[19]. Further, correlation between the BMD versus weight, height, age, and the duration of the post-menopausal period, respectively, was investigated. At last, a multiple regression analysis[20] was performed with the BMD taken as a dependent variable. Age, weight and the average annual solar radiation at the place of habitation were selected as independent variables, since verification had shown that they are mutually uncorrelated.

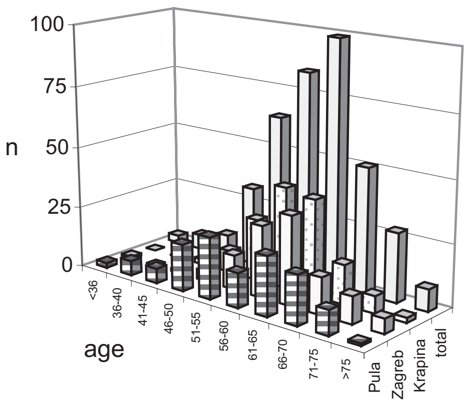

Fig. 1. Frequency distribution of the number of volunteers (n) regarding their age.

Results and Discussion

Figure 2 illustrates the dependence of the average BMD on the average annual solar radiation at the ground. One may see that the average BMD is proportional to the average incoming solar radiation. Therefore, the highest and the lowest average BMDs are related to Pula (0.469 g cm^{-2}) and Zagreb (0.433 g cm^{-2}), respectively. Similarly, as shown in the Figure 3, normal bones (t-score ≥ –1) occurred the most frequently in Pula, which, among investigated towns has the largest amount of incoming solar radiation. On the other hand, they were the rarest for Zagreb, where available solar radiation is the lowest.

Table 3 shows relative frequencies of normal (t-score ≥ –1.0), osteopenic (–2.5 ≤ t-score < –1.0) and osteoporotic bones

TABLE 2
A LIST OF AVERAGE CHARACTERISTICS OF THE EXAMINED VOLUNTEERS

Location	Pula	Krapina	Zagreb	Total
Number of volunteers	128	141	118	387
Age				
Average (years)	57.3	59.9	61.8	59.6
Number of data	127	141	117	385
Height				
Average (cm)	163.2	161.7	162.8	162.5
Number of data	124	131	118	373
Weight				
Average (kg)	69.0	72.5	69.9	70.6
Number of data	126	141	118	385
Menarche				
Average (years)	13.5	14.5	–	14.4
Number of data	2	128	0	130
Menopause				
Average (years)	47.6	48.3	49.7	48.8
Number of data	40	117	113	270
BMD				
Average (g cm^{-2})	0.4685	0.4628	0.4330	0.4554
Number of data	128	133	118	379

(t-score < –2.5), respectively. Again, it shows that the larger available solar radiation, the more frequent are normal BMD values. Osteopenic bones are the most often found in Zageb, while osteoporotic bones are found in Krapna. Further, frequencies of normal BMD values are rather similar for Krapina and Pula, as well as frequencies of pathological values. On the other hand, bones with t-score less than –1 are much frequently found in Zagreb, where compared to the other two towns, relative frequency of the pathological BMD is up to about 14% higher.

The independence of the BMD and the amount of available incoming solar radiation at the ground was tested by contingency table[19]. When creating the contingency table (not shown here), each woman was classified according to two criteria. The first is the BMD, which is classified as normal (t-score ≥ –1.0) or pathological (t-score < –1.0). The second is the amount of available incoming solar radiation in

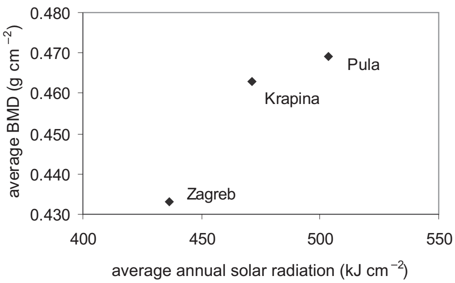

Fig. 2. Average bone mineral density vs. average annual solar radiation at the ground.

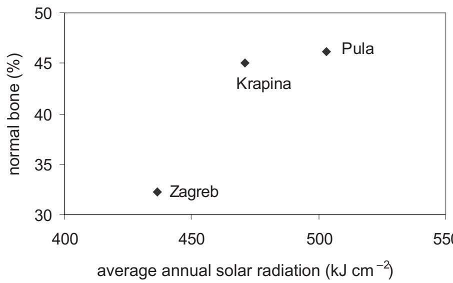

Fig. 3. The percentage of the normal bones vs. average annual solar radiation at the ground.

TABLE 3
RELATIVE FREQUENCY OF NORMAL (T-SCORE ≥ –1.0), OSTEOPENIC (–2.5 ≤ T-SCORE < – 1.0) AND OSTEOPOROTIC (T-SCORE < –2.5) BONES

Town	Normal bones (%)	Osteopenic bones (%)	Osteoporotic bones (%)	Pathological bones t-score < –1.0 (%)
Zagreb	32.2	61.0	6.8	67.8
Krapina	45.0	43.6	11.4	55.0
Pula	46.1	46.9	7.0	53.9

the volunteer's place of habitation, where Pula, Krapina, and Zagreb correspond to the higher, medium and lower amount, respectively. Result of the χ^2 test at the significance level α=0.05 shows that BMD depends on the amount of available incoming solar radiation at the ground. In other words, the larger available solar radiation, the more probable is the normal BMD, and, vice versa, the lower available solar radiation, the more probable is the pathological BMD. Obtained test result is also in accordance with results shown in Figures 2 and 3.

Figure 4 illustrates the dependence of the average BMD upon the age for Pula, Krapina, Zagreb, and all three towns together, respectively. It generally reflects the fact that the older the age, the lower is the BMD. Different picture for the ages less than 46–50 for Pula, Zagreb and total could rather be attributed to the small number of volunteers of that age, than to the general behavior. However, the decrease of the BMD with the age for Pula does not seem to be as pronounced as for other two towns and all three towns analyzed together.

A negative correlation between the age and the BMD is statistically confirmed for all three towns (Figure 5). Correlation is the highest for Krapina (correlation coefficient r = –0.33, level of significance α = 0.01, number of pairs n=132). Still significant, but weaker correlation (r = –0.17, α = 0.10), is obtained for both Pula (n=

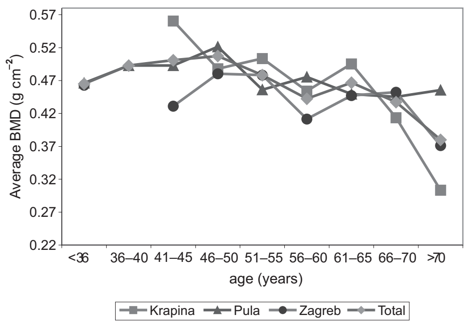

Fig. 4. Dependence of the average bone mineral density upon the age.

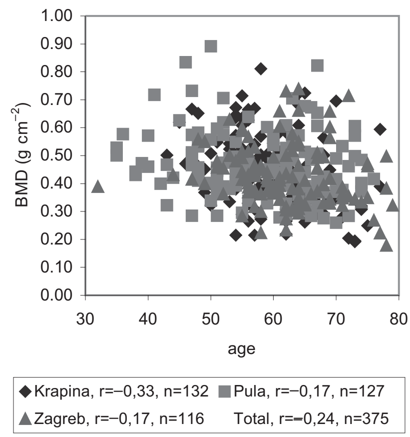

Fig. 5. Scatterplot of age vs. bone mineral density. Corresponding correlation coefficients (r) and numbers of pairs age-BMD (n) are also given. For Krapina and all three towns together correlation coefficients are significant at level α= 0.01, while for Pula and Zagreb they are significant at level α=0.10.

127) and Zagreb (n=116). Similarly, a statistically significant correlation coefficient ($r = –0.24$, $\alpha = 0.01$, n=375) is obtained for all three towns analyzed together.

Figures 6 and 7 illustrate the dependence of the BMD on the period after menopause. The decrease of the average BMD with the length of the period after menopause is the most obvious for Zagreb and all three towns investigated together, while for Pula and Krapina relationship does not seem to be so clear (Figure 6). However, if individual BMD data are analyzed (Figure 7), a statistically significant (α=0.05) negative correlation coefficient between the BMD and the period after menopause is obtained for all data sets except for Pula.

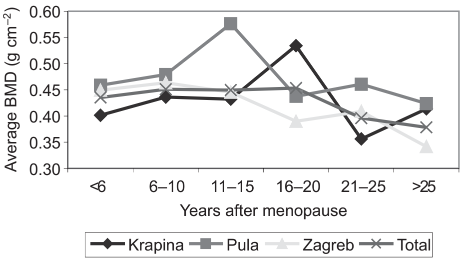

Fig. 6. Dependence of the average bone mineral density on the period after menopause.

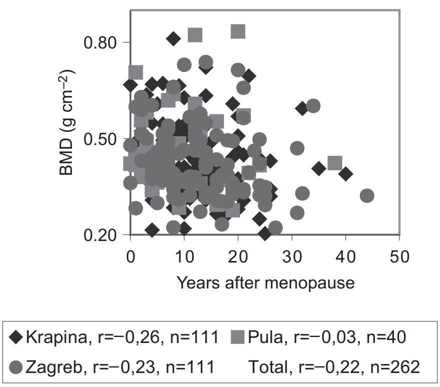

Fig. 7. Scatterplot of years after menopause vs. bone mineral density. Corresponding correlation coefficients (r) and numbers of pairs years-BMD (n) are also given. Correlation coefficients for Krapina, Zagreb and all three towns together are significant at level α=0.05. For Pula there is no correlation found.

The dependence of the BMD on the weight is shown in Figure 8. Statistically significant (α=0.01) positive correlation coefficients obtained for Krapina, Zagreb and all three towns analyzed together suggest that the higher the body weight, the larger is the BMD. Again, for Pula residents BMD does not seem to be dependent on weight.

Investigation of the influence of the woman's height on the BMD showed that there was no correlation between the height and the BMD for any of examined data sets.

The results of the multiple regression analysis using age, weight and average incoming solar radiation as predictors of BMD show that all three assumed vari-

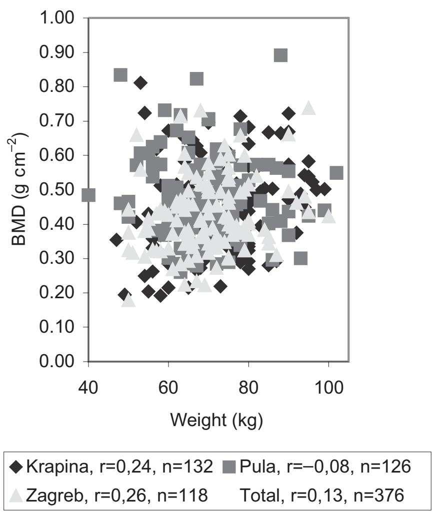

Fig. 8. Scatterplot of weight vs. bone mineral density. Corresponding correlation coefficients (r) and numbers of pairs weight-BMD (n) are also given. Correlation coefficients for Krapina, Zagreb and all three towns together are significant at level α=0.01. For Pula there is no correlation found.

ables significantly (α=0.05) explain variance of BMD, though obtained value of R^2 is rather low (R^2=0.08473896). The form of the outcome multiple regression equation is the following:

$$BMD=0.315189-0.003219*AGE+0.001515 * WEIGHT+0.000462 * AASR$$

where BMD is given in g cm^{-2}, AGE is in years, WEIGHT in kilograms and average annual solar radiation at the place of habitation (AASR) is expressed in kJ cm^{-2}. Above model reveals the major role of the AGE compared to other two predictors, while influence of the AASR is the lowest. Value of R^2 indicates that approximately 8.5% of the variance in BMD is explained by the AGE, WEIGHT and AASR. This also suggests that other factors contribute to BMD value.

Conclusions

Based on above results regarding female adult inhabitants of three Croatian towns (Krapina, Pula and Zagreb) following conclusions may be summarized:

1. Existing spatial variations of the average incoming solar radiation at the ground in Croatia seem to be large enough to result in different average BMD depending on the place of habitation.
2. Both the average BMD and the probability of normal bone occurrence increase with the increase of incoming solar radiation. Consequently, the highest average BMD was obtained for Pula (0.469 g cm^{-2}), and the lowest for Zagreb (0.433 g cm^{-2}). Further, the normal bones were the most frequent in Pula (46.1 %) and the most rarely found in Zagreb (32.2 %).
3. Osteopenic bones were the most frequently found in Zagreb (61.0%), while corresponding figures for Pula and Krapina were 46.9% and 43.6%, respectively. Osteoporosis varied from 6.8% in Zagreb to 11.4 % in Krapina.
4. There is a statistically significant negative correlation between the age and BMD.
5. There is no correlation between BMD and height.
6. Apart from Pula, a statistically significant negative correlation between BMD and years after menopause is found.
7. Apart from Pula, positive and statistically significant correlation of BMD and body weight is found.
8. We believe that acquired results for Pula may to the great extent be attributed to large insolation and consequent D vitamin production in skin, which reduces the negative effects of the period after menopause and the low body weight on the BMD.
9. Results of the multiple regression analysis indicate that BMD depends on the age, weight and available solar radiation at the place of habitation. They also suggest the need for further investigation of other possible individual and/or lifestyle and environmental factors (such as nutrition habits, air and water pollution etc.).

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UTJECAJ DOLAZNOG SUNČEVOG ZRAČENJA NA MINERALNU GUSTOĆU KOSTIJU ODRASLE ŽENSKE POPULACIJE U HRVATSKOJ

SAŽETAK

Ispitana je veza između mineralne gustoće kostiju (BMD) u odraslih Hrvatica i dolaznog sunčevog zračenja pri tlu. U studiji je dobrovoljno sudjelovalo 387 žena prosječne starosti 60 godina iz tri različita grada: Pula (n=128, dob od 35 do 76), Krapina (n=141, dob od 43 do 77) i Zagreb (n=118, dob od 32 do 79). Osim po različitom životnom stilu, svaki od ovih gradova razlikuje se i po različitom dolaznom sunčevom zračenju, gdje se vrijednosti od 503.3 kJ cm^{-2}, 471.2 kJ cm^{-2} i 436.3 kJ cm^{-2} odnose na Pulu, Krapinu i Zagreb. BMD petne kosti je mjerena ultrazvučnim denzitometrom (Sahara). U prosjeku je BMD bila najveća za Pulu (0.469 g cm^{-2}), a najmanja za Zagreb (0.433 g cm^{-2}). Slično, postotak normalnih kostiju bio je najveći u Puli (46.1%), a najmanji u Zagrebu (32.2%). Osteopenija je bila najčešća u Zagrebu (61.0%), dok se u Puli i Krapini pojavila u 46.9%, odnosno 43.6% slučajeva. Osteoporoza je varirala od 6.8% slučajeva u Zagrebu do 11.4% u Krapini. Test za nezavisnost u tablici kontingencije potvrdio je na razini signifikantnosti α=0.05 da je vjerojatnost da kost bude normalne gustoće to veća što je dolazno sunčevo zračenje veće. Rezultati analize višestruke regresije sugeriraju ovisnost BMD o ženinoj starosti i težini te o prosječnom dolaznom sunčevom zračenju u mjestu boravka.